Progress on the ELM Simulating Plasma Gun

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Overview

- Need for an ELM simulator
- Existing experiments
- ELM Simulating plasma gun Experimental Setup
- Phase I and Phase II goals
- Present status of Phase I experiment
- Issues and Future Plans

The Need for an ELM Simulator

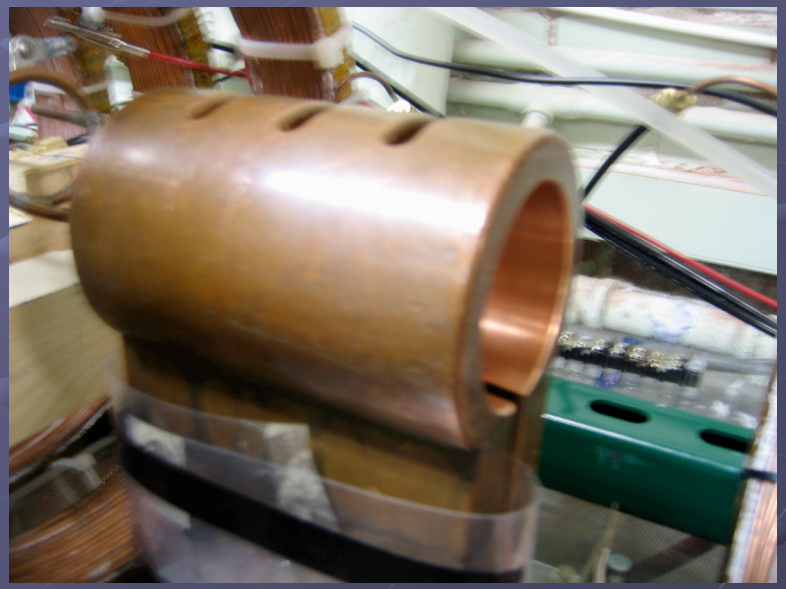
- Edge Localized Modes (ELMs) are the greatest challenge to plasma facing components (PFCs)
- ELMs deliver both a cyclical high heat flux and a high plasma particle flux
- A means of simulating the effects of ELMs on candidate PFCs is needed both for ITER and domestic experiments, such as lithium PFCs

What is already out there

- SNL has an e-beam source capable of simulating ELM heat fluxes
  - Provides a means of simulating cyclic thermal loading over long time periods with appropriate energy deposition profile
  - A long-duration lifetime test and high heat flux qualification facility
- Plasma gun simulator can complement this effort by allowing quantification of surface erosion by plasma interaction in conjunction with high heat flux
- Russian plasma guns exist for disruption simulations
  - Time-scale/heat flux combinations miss ELM target, but modifications are underway to provide ELM simulating capability
- A domestic ELM simulation facility is desirable
  - Verification of results for ITER relevant materials
  - Greater flexibility of US PFC program for studying advanced materials and PFC concepts
  - Quicker results by working in parallel – there is more than enough work to occupy a few ELM simulators scattered around the globe

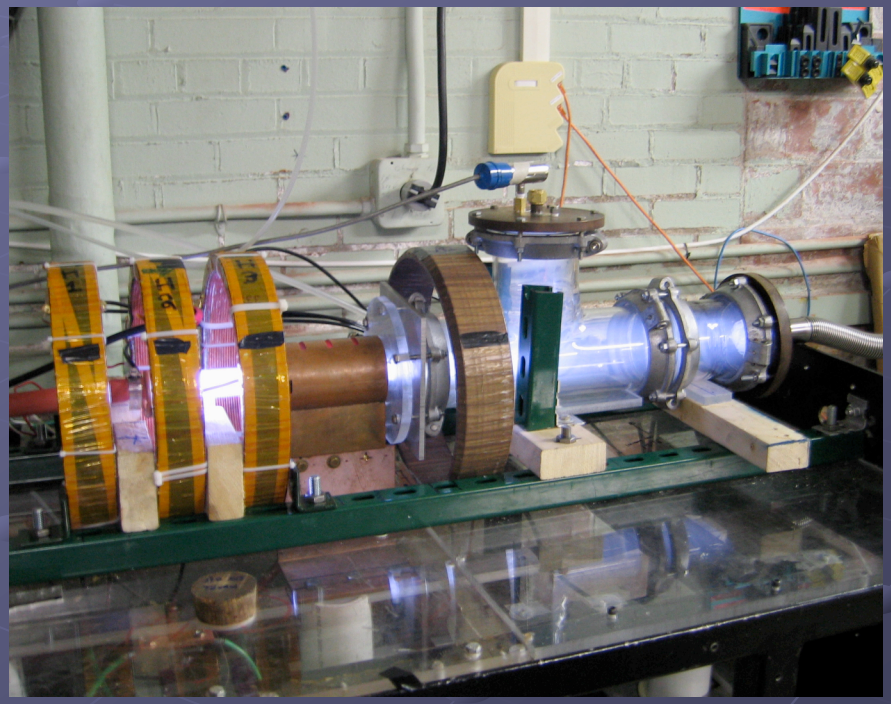
The Starfire-UIUC ELM Simulating Plasma (ESP) Gun

- Conical theta pinch with under-damped sequentially-fired pulse forming networks (PFNs)
- Underdamped “ringing” PFNs provide multiple pinches rapidly, allowing the use of only a few PFNs
- Multiple PFNs fired sequentially further extends plasma blob stream to ELM time scales (~1 ms) and allows some temporal shaping



Preionization Source

- Helicon preionization source provides dense conductive plasma with rapid replenishment
- Guiding field simulates divertor fields
  - Contains expelled plasma, minimizing density and temperature degradation due to plasma expansion
  - Higher fields help helicon preionization source
  - Stronger field would help increase density and temperature

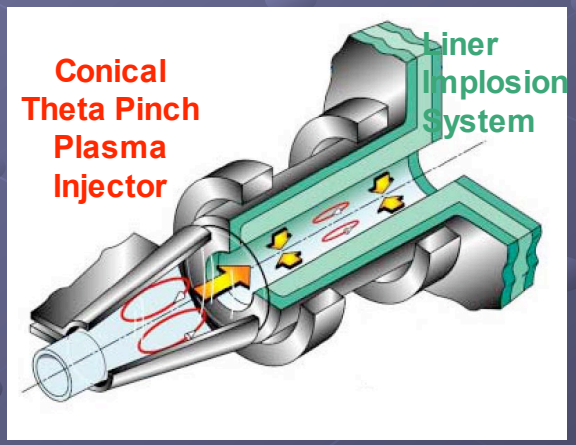


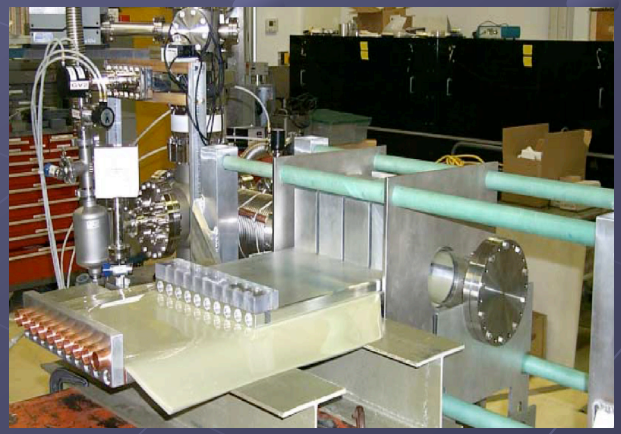
Desired Simulation Characteristics

- Near-term (~6 month) goal is NSTX-level simulation
  - Densities ~$10^{19}/m^3$
  - Temperature ~200 eV
  - ELM blob-stream duration ~0.5-1ms
- Long-term (1-2 year) goal is ITER-level simulation
  - Densities ~$10^{20}/m^3$
  - Temperature ~1keV
  - ELM blob-stream duration ~1ms

Can This be Done with Existing Equipment?

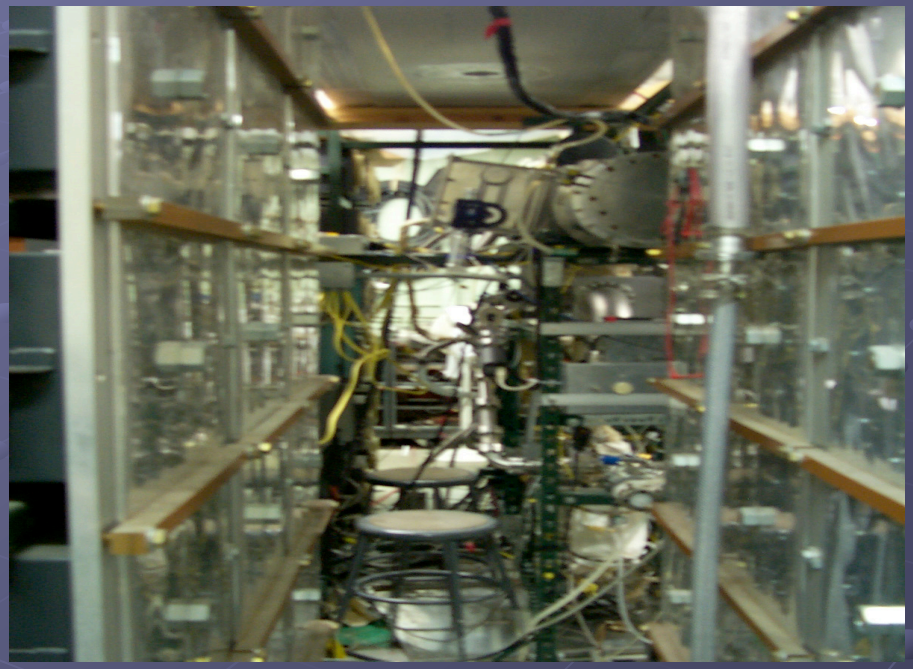
- Compare to existing conical theta pinch experiment
- FRX-L presently uses a conical theta pinch to generate and translate target plasma into their liner-implosion chamber
  - 1MJ capacitor bank
  - Present densities ~3-5X10^{22}/m^3 (1X10^{23}/m^3 is expected)
  - Present temperature ~200 eV
  - Plasma lifetime ~20μs
  - Main theta pulse is crowbarred after first cycle of pulse – remaining energy is dumped





Can This be Done with Existing Equipment? (continued)

- In ITER case, ESP gun requires ~1/1000th the density planned in FRX-L target plasma (before liner implosion)
- Temperatures in ITER ESP gun would be ~5X higher and duration would be ~50X longer
- The resulting required energy storage, assuming the same energy efficiency as FRX-L, is ~1/4 MJ
- UIUC has a 1/4 MJ high-voltage capacitor bank that will be used for ITER-level ELM simulations
- 36 MJ bank presently in use may be feasible for NSTX-level ELMs (more on this later)



Efficiency

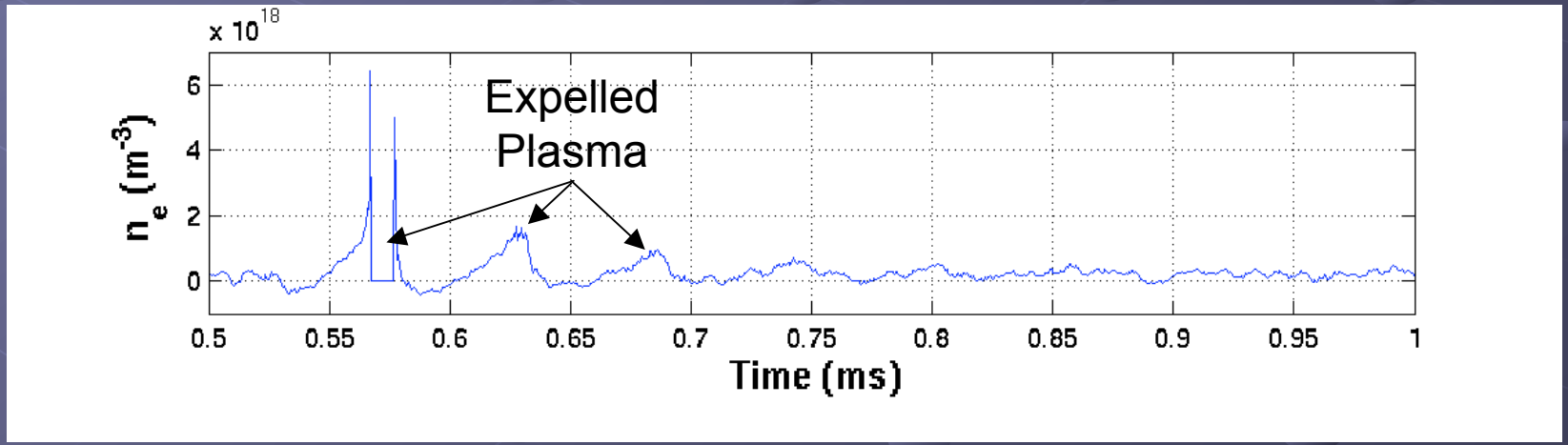
- FRX-L crowbars reflected pulse energy, using only the initial cycle of the pulse
- The Starfire-UIUC ESP gun uses ringing PFNs that deposit a higher fraction of stored energy into the plasma – We may have more than we need
- Based on this energy analysis, existing equipment should be capable of reaching ITER-level ELM simulations, as well as the near-term NSTX level ELM simulations

Small Capacitor Bank

- Experiments to date carried out with 16-kV 36kJ capacitor bank (6 54-μF capacitors)
- Initial tests used only two capacitors, each operating independently at <8 kV
- Later tests carried out with 3 capacitors in parallel, operating at <10 kV
- Capacitors are capable of 16-kV operation, only 40% ($10kV^2/16kV^2$) of their energy storage capacity has been used.
- Each capacitor has an inductance ~500 nF

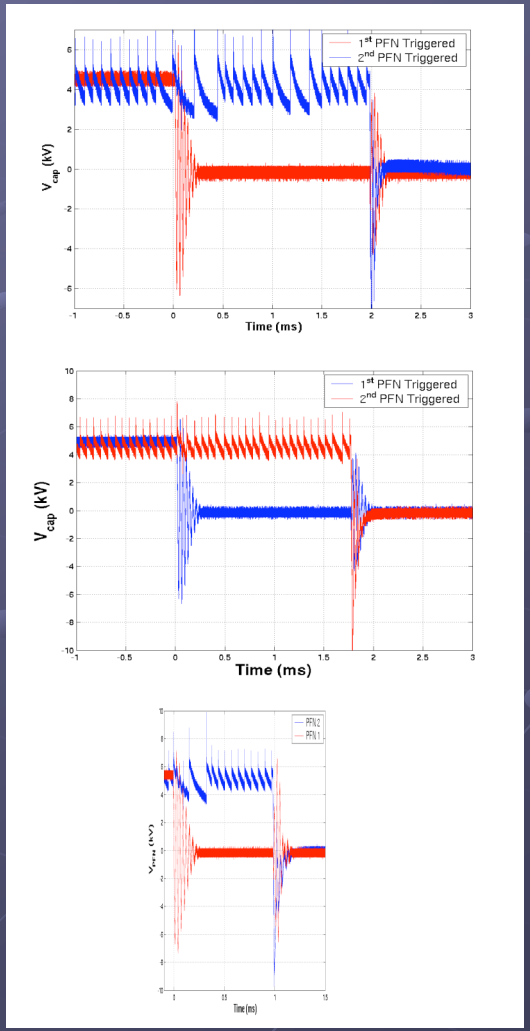
Multiple Pinches from Single Ringing PFN, Plasma Translation

- Multiple plasma blob ejection from a ringing PFN has been demonstrated in ESP gun
- More efficient utilization of stored energy
- Lengthens attainable time scale while using only a few PFN's
- Detection with down-stream triple probe demonstrates plasma translation



Ability to Time and Fire Multiple PFNs

- The ability to fire multiple PFNs independently has been demonstrated
- Time between pulses can be controlled
- Can be combined with multiple PFNs to deliver desired 1 ms pulse stream



Summary of Present Development Status

- Conical coil machined and installed
- Helicon preionization source operational
- Sequential firing/timing demonstrated with 2 capacitors
- Translation of plasma from conical coil region to probe and target location demonstrated
- Multiple plasma blob ejection with ringing PFN demonstrated

Issues to be Addressed

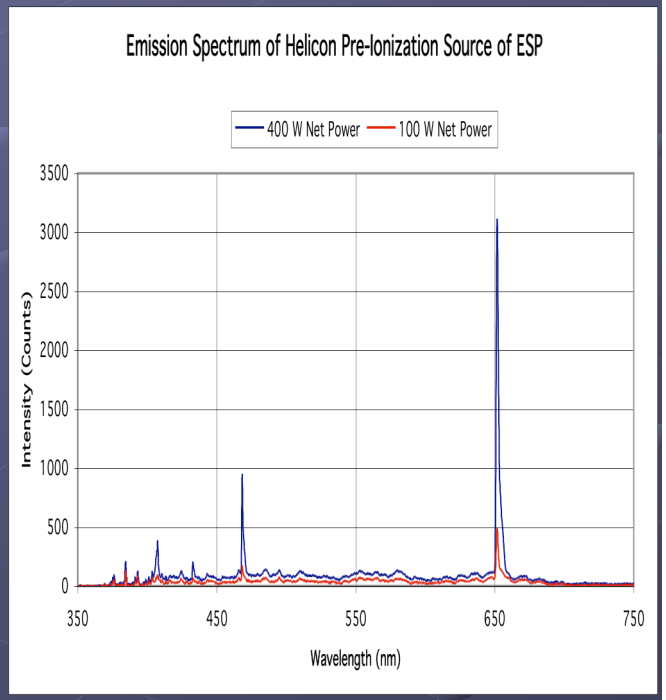
- DC Magnetic field strength needs to be larger to simulate divertor edge field
- Density and temperature are lower than desired
  - Increase DC field strength to improve confinment and helicon plasma density
  - Increase pulse rise time
- System inductance (vast majority in capacitors) is high
  - Use higher voltage to increase current rise time
  - Use capacitors from large bank (much higher voltage and lower inductance)
  - Can pulse shaping techniques be applied (saturable inductors for example)?

Issues to be Addressed (continued)

- Tests have only been carried out up to 10 kV with 16 kV capacitors, less than ½ of their energy storage capability
- Target mount and heating mechanisms needs to be built
  - Inductive heating looks promising
  - E- beam heating is another possibility
  - If B-field is increased, helicon plasma source may suffice for steady state heat flux

Diagnostics (What we have or can Build)

- Triple Langmuir Probe is built and in use
- IR Heat Flux diagnostics
  - IR measurement circuit is being built for 1-5μm PbSe detector
  - Response time is slow (>3 μs for PbSe photoconductors, faster for shorter-wavelength detectors)
  - Heat transfer model may be needed to calculate actual heat-flux based on measured IR data and good knowledge of detector response time
- Optical Spectroscopy diagnostics
  - Existing spectrometers can be used for time-averaged temperature measurement
  - Acquisition time of spectrometers is ~3 ms
  - Timing can be synchronized with pulse (timing circuit being built)



Conclusions

- Several critical issues for success of ESP gun development have been addressed
  - Ringing PFN can be used to generate rapid plasma pulse stream
  - Plasma can be translated from gun region to target region
  - Desired pulse lengths should be achievable
- Additional critical issues have been identified and are being addressed
  - Need higher magnetic field strength
  - Need faster rise time (several options exist for dealing with this)
  - Higher density and temperature should result from combination of these to improvements
  - Need to design target mount and heat target

Conclusions (Continued)

- Rudimentary diagnostics exist or are being developed
  - Triple Langmuir probe (exists)
  - Spectroscopy (developing)
  - Primitive IR temperature diagnostic (developing)
- Additional diagnostics and materials are needed to make ESP gun test stand into a world-class PFC ELM testing and qualification facility
  - QCM
  - Fast visible and/or IR camera
  - Fast Spectrometer
  - See David Ruzic's Presentation, Tuesday afternoon